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DEVELOPMENT AND TESTING OF IMPROVED TECHNIQUES FOR MODELING THE HYDROLOGIC CYCLE IN A MESOSCALE WEATHER PREDICTION SYSTEM

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13. ABSTRACT (Maximum 200 words)

This research addresses the problem of moisture and temperature initializations in regioal scale meteorological prediction models. Speifically, two approaches are used: one involving radar data and the second involving improved soil moisture content information. The model is initialized with rawinsonde data and then is forced to match convective signatures identified from WSR-57 radar data. Data from NOAA AVHRR radiometer data is used to initialize soil moisture information and generate large scale moisture fields. Methods of continuously updating soil moisture fields are under development

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"Development and Testing of improved techniques for modeling the hydrologic cycle in a mesoscale weather prediction system"

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1. Introduction

This research addresses two specific facets of one general problem, that of initialization of a regional-scale atmospheric prediction model to produce optimum fields of surface humidity and temperature. One facet involves using radar data to predict the correct location, timing and intensity of cumulus convection. The other is a method to initialize the model with the correct soil water content. These initialization schemes are closely related in that they both seek to produce fields of surface temperature and humidity, without which important convective outbreaks and their attendant precipitation patterns can not be accurately predicted. Such patterns are intimately dependent on a detailed and accurate knowledge of the small-scale distribution of surface equivalent potential temperature, θ_e, which is a function of both temperature and humidity. As such, the two types of initialization schemes have similar objectives, in that each is concerned with improving the surface moisture fields with the aid of remote measurements.

The first approach to initializing these fields uses radar reflectivity data to nudge on a somewhat interactive basis the simulations (forecasts) in the direction of the observations. The other approach uses a hydrology model to produce initial soil water content, on which values of components in the surface energy balance are highly dependent. A new, and as yet untested improvement to the standard approach of using a hydrology component alone is based on the incorporation of estimated soil water content measurements obtained from the NOAA/AVHRR satellite radiometer (surface resolution about 1 km). These remotely derived estimates of surface soil water content

will be integrated with the hydrology estimates over a grid for inclusion into the land surface component of the Penn State/NCAR mesoscale model.

The remainder of this report will summarize the advances made over the past year in realizing these new initialization techniques. The next section summarizes the method for incorporating radar reflectivity in the initialization scheme. Section 3 summarizes the advances using the hydrology model and satellite measurements for initialization scheme. Section 4 presents a brief overview of where the research in presently headed.

2. A Procedure for Using Radar Reflectivity Data to Locate Convection in The Dynamic Initialization of a Mesoscale Model

a. Summary of Research

The objective of this research is to improve the Penn State/NCAR mesoscale model (MM4) forecast of the location and timing of convection. The model is usually statically initialized with convectional rawinsonde data, but the large distance between the rawinsonde sites may very likely obscure any localized convective forcing mechanisms. Radar reflectivity data, however, can provide information about the location of convection with high spatial and temporal resolution over a large area. In this study, radar data are used in a pre-forecast period, where the radar data define the location of convection. The convective parameterization scheme (CPS) in the model then calculates the convective effects at those locations, so that at the initial forecast time the areas of convection and its effects will be in the correct locations.

b. Procedure

Digitized, low-level 0.5° elevation angle) scan radar data from 5 WSR-57 radars equipped with the RADAP II digitizer are used to locate convection in the model for the 10-11 June 1985 PRE-STORM squall line. The scans occur every 10 minutes and are

assimilated at that frequency in a pre-forecast period beginning at 12UT 10 June. However, the model grid is not completely covered by the radar scans. The CPS will locate and produce convection and its effects at these grid points according to the model conditions.

The CPS and radar data often concur on the location and timing of convection, but when they do not agree, the model is forced to be in agreement with the data. When the radar shows no convection at a particular grid point but the CPS calculates that there should be, convection will simply be turned off at the location. At grid points where the radar shows convection but the CPS does not, a certain model layer of air below 300 mb above the ground (either the layer with the highest θ_e value (TM) or the layer with the least amount of negative area to overcome (NA)), is lifted to its level of free convection (LFC) to initiate convection. If this fails to produce a cloud a least 4 km deep, a small amount of moisture is added to the layer to increase its buoyancy, and the process is repeated. If a deep cloud is to initiated after a certain amount of moisture is added, the forcing is stopped and no cloud is formed at that grid point.

There are a total of 8 model integrations: 2 'control' runs (no assimilation) and 6 assimilation runs. All runs are initiated with conventional rawinsonde data. The first control run is an 18 hour forecast (C18) initiated at 12UT 10 June, and the second is a 6 hour forecast (C6) initiated at 00UT 11 June. The 6 assimilations runs are all initialized at 12UT 10 June with conventional rawinsonde data: 3 use the TM method of forcing and the other 3 use the NA method. For each method, the first run assimilates data for 6 hours and produces a 12 hour forecast (TM6, NA6), the second assimilates data for 9 hours and produces a 9 hour forecast (TM9, NA9), and the third assimilates data for 12

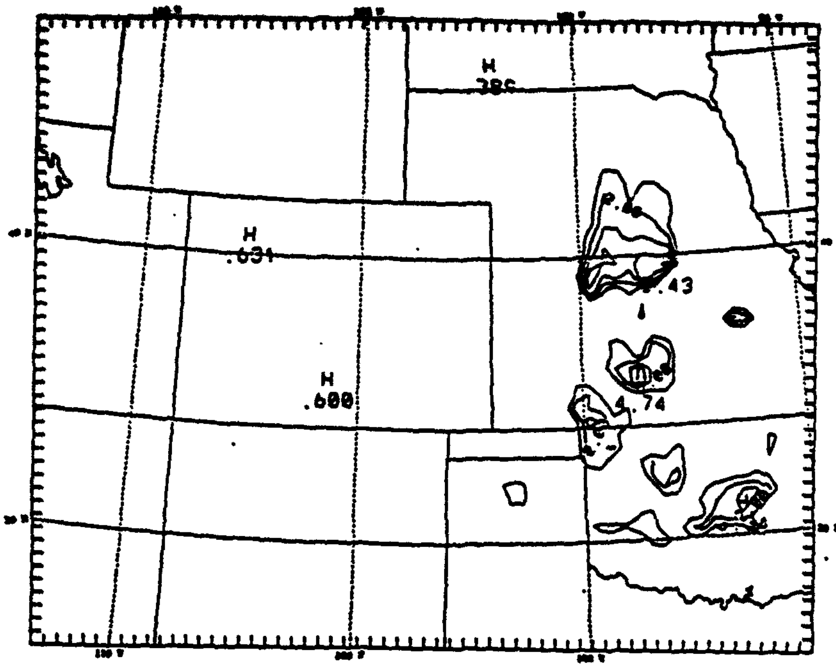
hours and produces a 6 hour forecast (TM12, NA12). All forecasts end, obviously, at 06UT 11 June.

c. Results

In C18, convection is initiated by the model in central Oklahoma and the Texas panhandle between hours 5 and 9 (17UT to 21UT 10 June) that is not evident in the observations; it continues until hour 15 (03UT 11 June). Results from the 6 assimilation runs show that TM6, NA6, TM9, and NA9 suppress the spurious convection during the assimilation pre-forecast period, as they should, but the convection initiates after the assimilation periods end. Only in TM12 and NA12 does the convection not occur after the pre-forecast assimilation period ends. This would suggest that some erroneous strong local- or large-scale model forcing is occurring in this area over a 10 hour period that can only be suppressed by changing the local convective activity in the first 7 hours of its existence.

Figure 1 and 2 show the simulated hourly convective rain accumulations of C18, TM12, and NA12 for the periods ending at 17UT 10 June and 00UT 11 June, respectively. A comparison of Figure 1a(C18) to 1b(TM12) and 1c(NA12) clearly shows that the erroneous convection in central Oklahoma was suppressed by the radar data in both the TM and NA data assimilation cycles. Figure 2 displays similar results for the erroneous convection in the central Texas panhandle.

A large area of convective precipitation is evident in the first hour of C6 over western Kansas and Oklahoma (Fig. 3a) in a more or less north-northwest/south-southeast oriented line turning east into central Oklahoma at its southern end. According to the observations the squall line had a northeast/southwest orientation that



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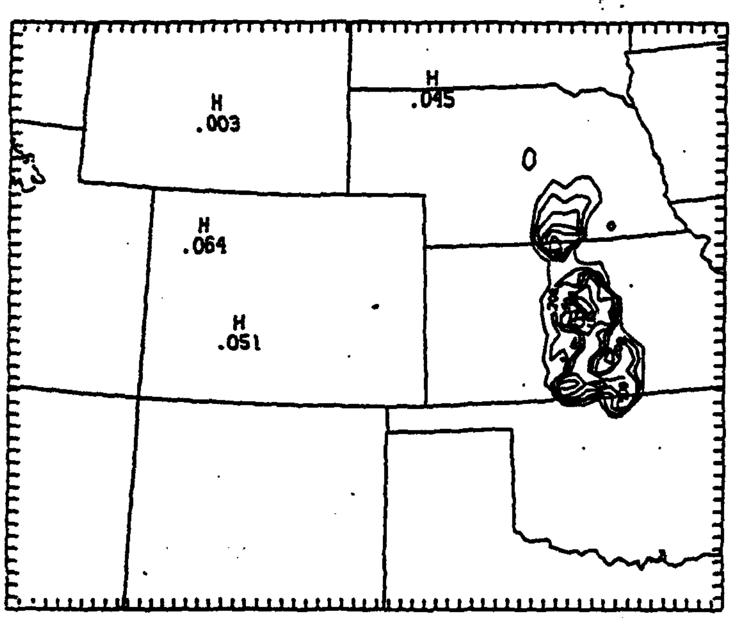

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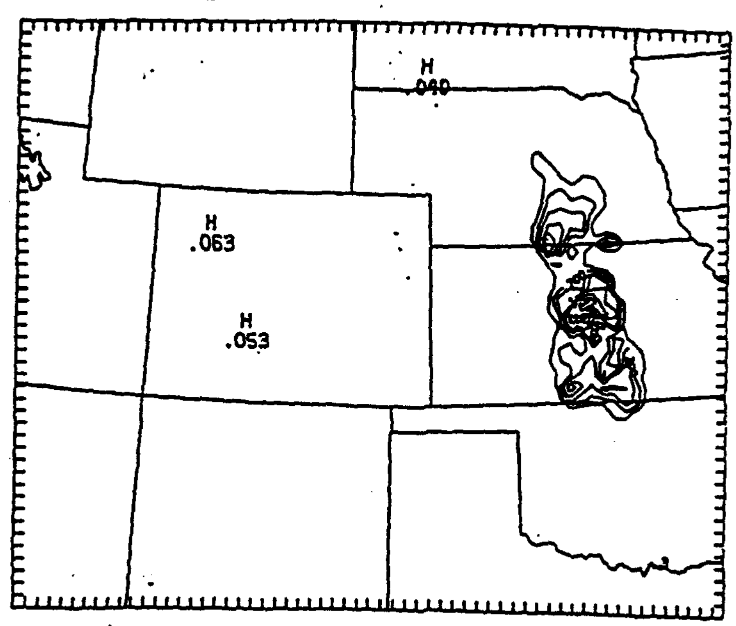

1c

Figure 1. Simulated convective rain from 16UT-17UT 10 June 1985, isohyets every 1mm (labelled in cm in 1b and c). 1a) C18. 1b) TM12. 1c NA12.

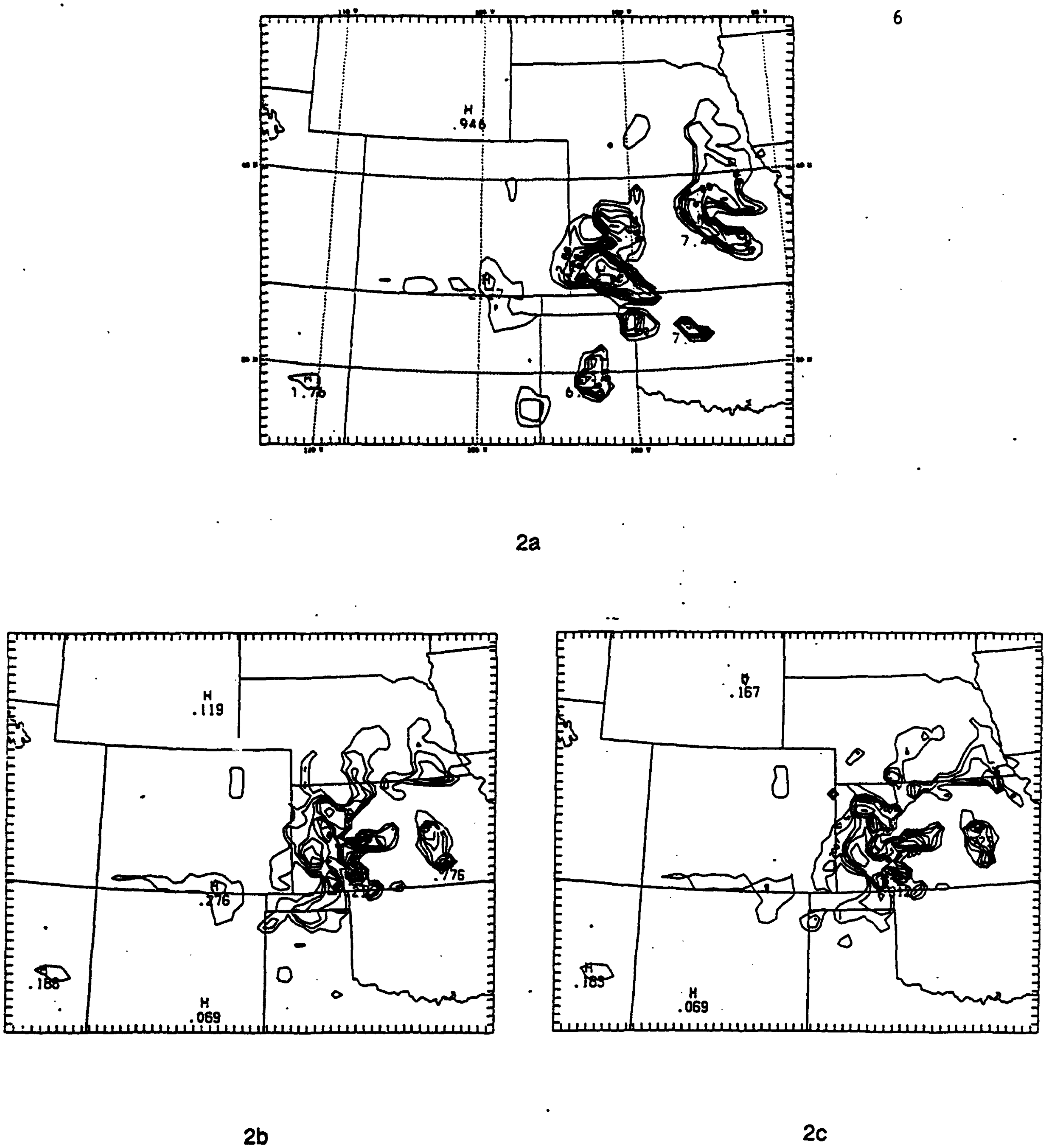

Figure 2. Simulated convective rain from 23UT 10 June to 00UT 11 June, 1985, isohyets every 1 mm (labelled in cm in 2b and c). 2a) C18. 2b) TM12. 2c) NA12.

extended from northern Kansas into the Texas panhandle at this time. Both the TM12 and NA12 1 hour forecasts produce convective precipitation over a larger area than was observed (Figs. 3b and 3c), but they do produce the correct observed orientation and approximate location of the squall line.

3. Initialization of Soil Water Content for Regional-scale Atmospheric Models

a. Procedures

Systematic inclusion of soil water content into the surface (BATS) component of the Penn State/NCAR mesoscale atmospheric prediction model has proceeded with the following steps.

1. Development and testing of a surface hydrology model.

2. Extension of the hydrology model to cover a horizontal grid domain corresponding to that of the mesoscale model.

3. Generation of large-scale fields of soil water content for the initial conditions of the mesoscale model.

4. Execution of the mesoscale model with the initialized soil water values.

5. Development of an operational method for continuously updating the initial soil water content fields from current meteorological data, such that the initial soil moisture fields will always be ready for inclusion in the mesoscale model.

6. Linking remote estimates of surface soil water content and fractional vegetation cover derived from satellite to the hydrological model, such that the initial fields inserted in the mesoscale model are modified by satellite measurements.

7. Testing the combined surface and satellite approaches by comparing the predicted and observed afternoon surface air temperatures for a number of case studies.

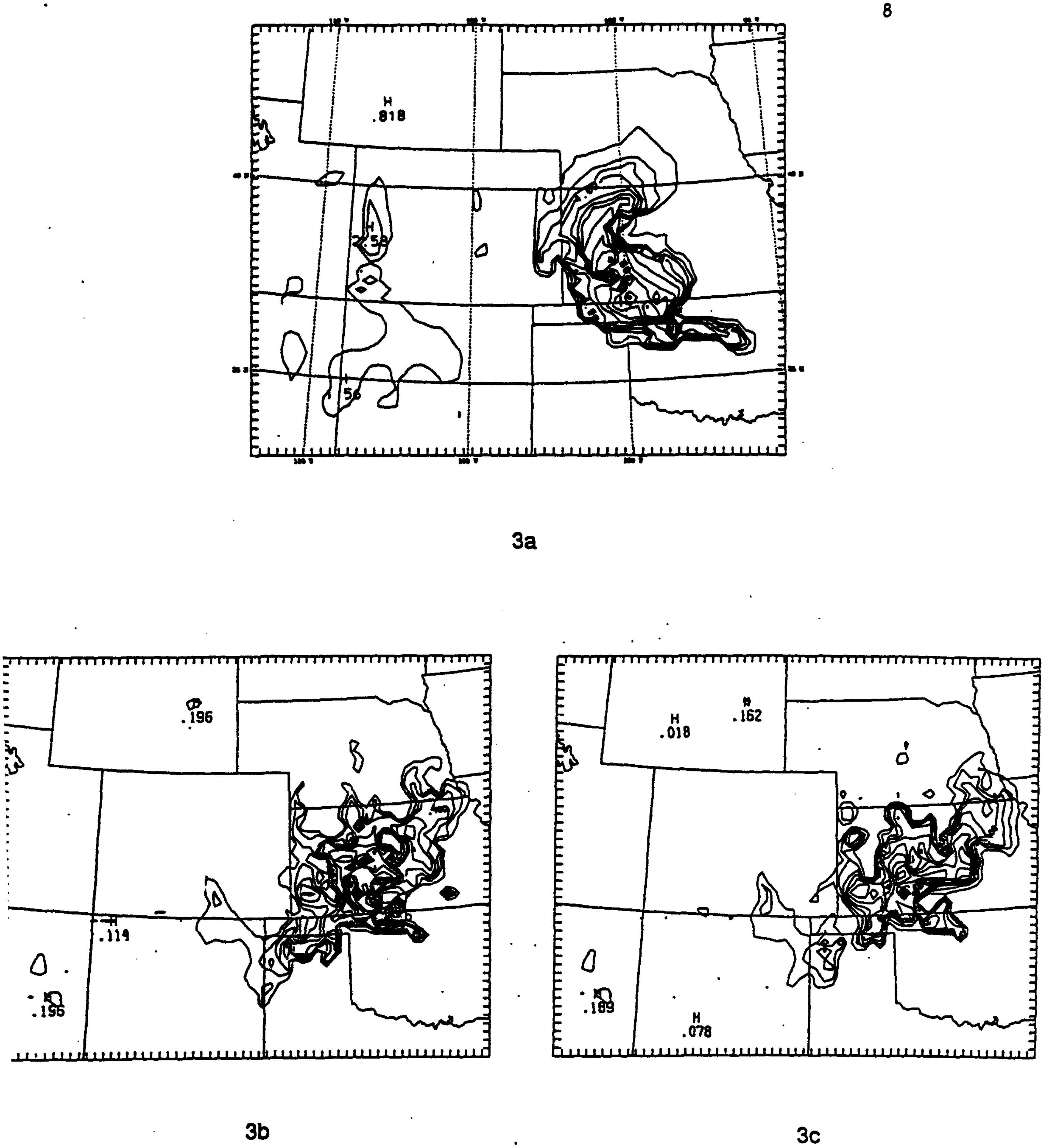

Figure 3. Simulated convective rain from 00UT to 01UT 11 June 1985, isohyets every 1 mm (labelled in cm in 3b and c). 3a) C6. 3b) TM12. 3c) NA12.

b. Current status

Development of the surface hydrology model (item 1) is now complete. A full description of the model along with some verification is presented by Capehart and Carlson (1994). Items 2, 3 and 4 have also been completed and are described in detail by Smith et al. (1994). As the result of the work by Smith et al., a short (in color) video film has been produced with the aid of NCAR showing the evolution of the surface and deep-layer soil water content during a four-month period over the northeastern United State prior to the initialization of the Penn State mesoscale model for a day in July, 1990. A copy of this video is available.

Attention is now being directed toward the last three items referred to above. As a preliminary step toward completing item 5, we have begun to test the hydrology model using current weather data (rather than archived data as described by Smith et al. (1994)) for a single grid point in the mesoscale model. Weather information obtained from the high-speed data line at Penn State is fed continuously to the hydrology model for a fixed grid point but with differing local conditions--soil type, crop species and fractional cover. Once this phase of the work is completed, step 5 can be continued by incorporating daily weather to a full array of grid points covering much of continental United States. This array will correspond exactly to the operational grid of the mesoscale model. It is anticipated that completion of this step will take place by the end of 1994.

4. The Future

A unique aspect of the present study is the incorporation of surface soil water content estimates derived from satellite into the hydrology model. More precisely, this

will be done by using the satellite estimates of surface moisture availability to modify (or 'nudge') the values obtained from the hydrology model. Step 6 is partly completed, insofar as the technique for deriving the surface soil water content values from satellite has been established and tested. Figure 4 shows how the procedure works. Normalized difference vegetation index (NDVI) measurements from the NOAA Advanced Very High Resolution Radiometer (AVHRR) and radiant surface temperature are combined using a soil/vegetation/atmosphere transfer (SVAT) model (whose output is represented by the isopleths in the middle figure) to produce fields of surface moisture availability M_o. Fractional vegetation cover is also derivable from the same procedure.

What remains to be done is to develop a systematic procedure for nudging the hydrology model output. A possibly difficult problem to overcome is that the satellite method is able to derive only surface soil water content values, whereas the BATS component in the mesoscale model requires both a surface and a deep layer soil water content for each grid point. Extending the satellite soil water content estimates to deeper layers remains a problem to be solved.

By 1996 we should have the capability of initializing soil water content for the mesoscale model from current weather data on any scale desired down to a few kilometers or less. Later, a weak link in the surface hydrology scheme, which is the unreliability and unrepresentativeness of the precipitation record, may be rectified using precipitation measurements obtained from radar. At that point, satellite, soil hydrology, atmospheric prediction models and radar will be coupled.

In order to verify the utility of the soil water content values, a series of case studies will be undertaken in which predictions will be made with the mesoscale model.

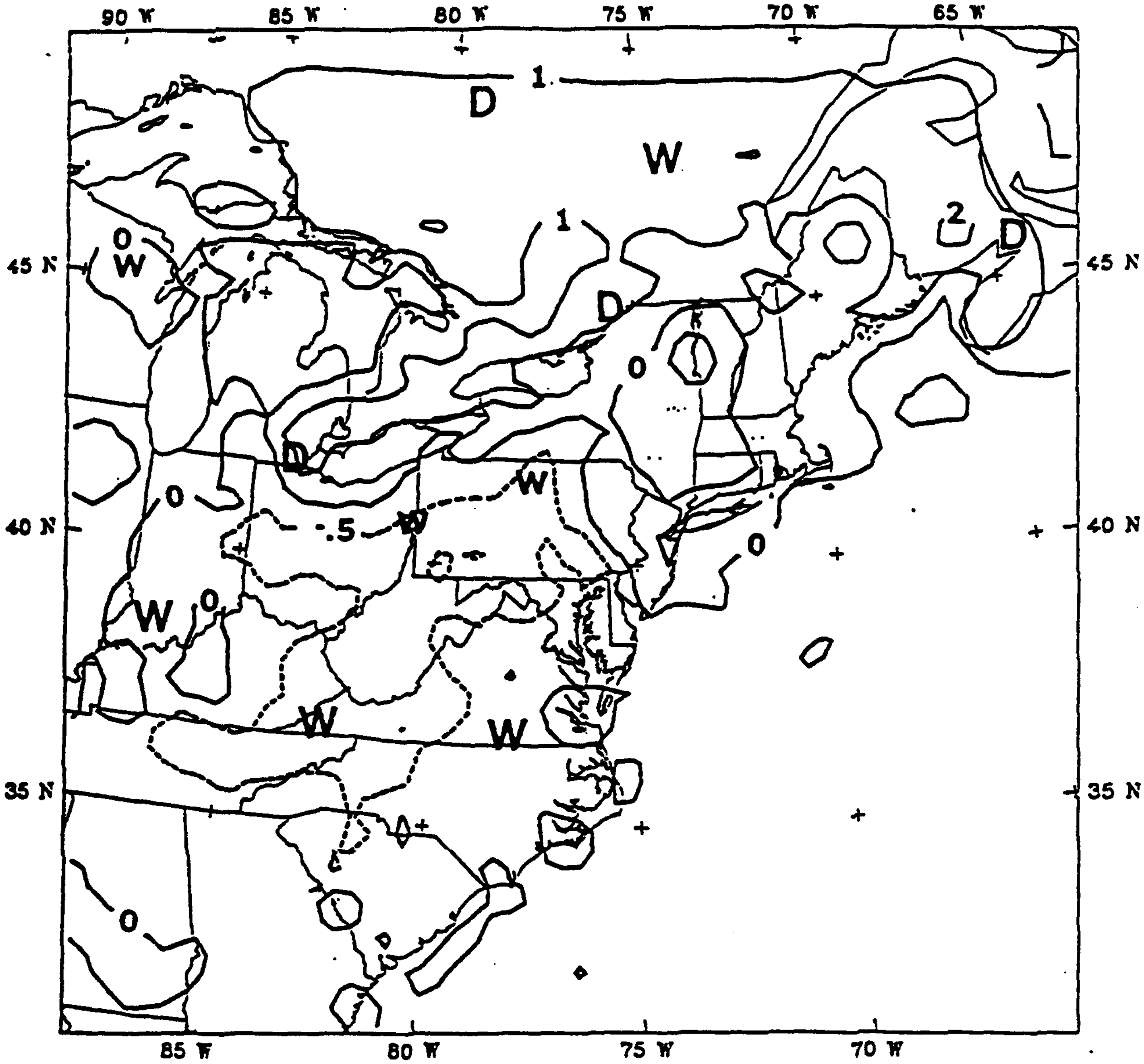

Figure 4. Scheme for producing images of surface moisture availability (output; M_o) from input fields of normalized difference vegetation index (NDVI) and radiometric surface temperature (T_o). Analyses are based on AVHRR measurements over the Mahantango Watershed area in Pennsylvania, 5 June 1990.

Afternoon maximum temperature, which directly responds to changes in the soil water content, will be used as verification. Figure 5 shows the afternoon temperature differences for a 12 hour simulation with the Penn State mesoscale model between fields generated from soil water content derived from the hydrology model and those for climatological soil water content. Clearly, because of the noise inherent in such simulations and the influence of other parameters, a large number of such simulations must be made before validation is assured. These tests will begin about the end of 1994.

Regarding the radar work, a more thorough examination of the pressure, 3-D velocity, temperature, and other fields will be done to see how well the simulations compare to those aspects of the observations, and to see which forcing routine, TM or NA, produces the best forecast.

Completion of the present goals will occur sometime during 1995 or early 1966 with the integration of the remote measurements and the operation meteorological observations with the hydrology and mesoscale meteorological models. Thereafter emphasis will be made on using the combined package to study different types of mesoscale or regional-scale phenomena with the soil water content initialization. We are also giving some thought to using the moisture availability and fractional vegetation cover derived form satellite to study changes in microclimate brought about by changes in land use, such as from urbanization of deforestation. A current and future emphasis for the remote sensing side of the project, is in verification of the methodology--a task that will require an additional two or three years.

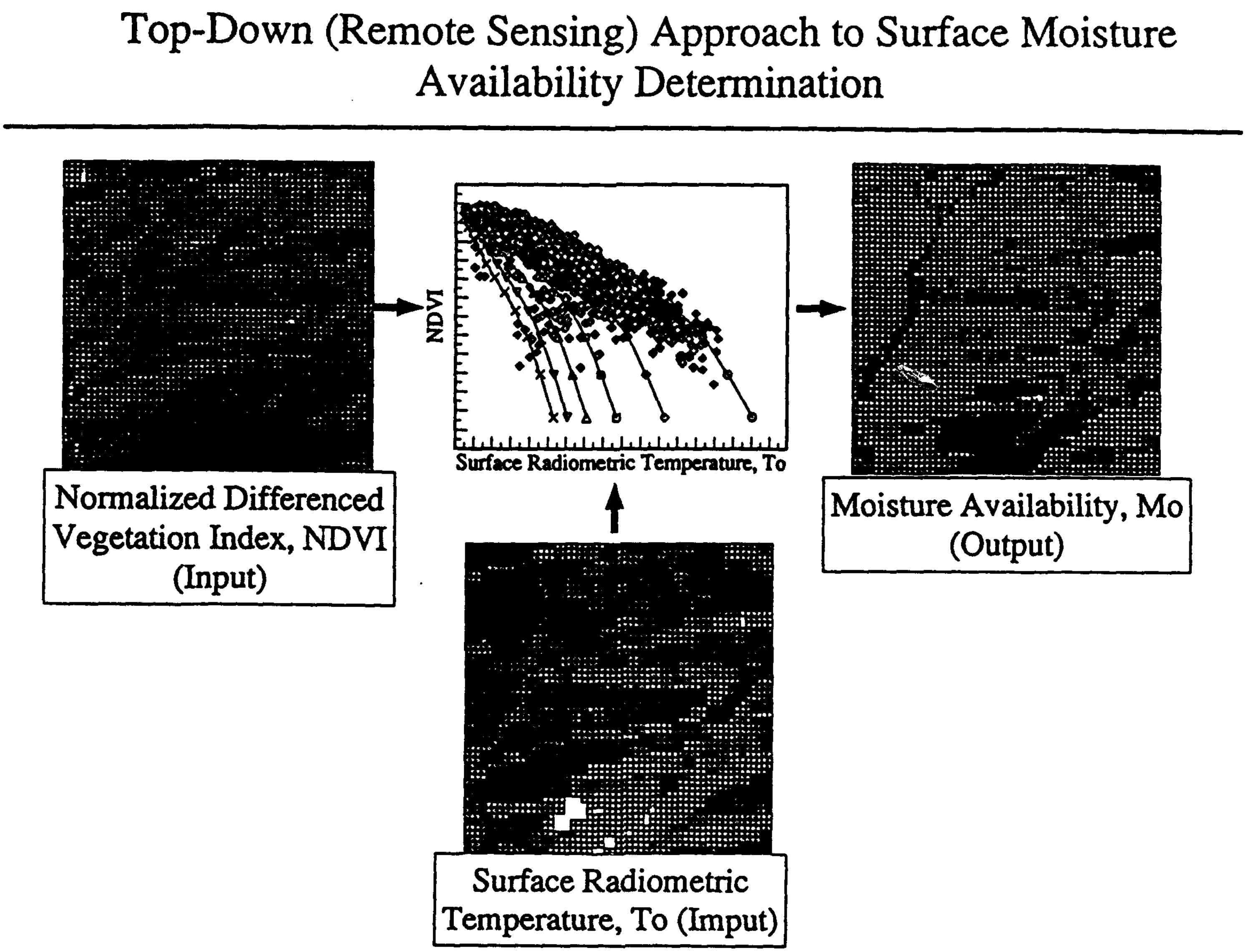

Figure 5. Difference between the Penn State/NCAR mesoscale model surface temperature results for 18 UTC 17 July 1990 (6 h into simulation, approximately 1400 local time) using the climatological soil moisture values and the values produced by the hydrology model. The contour intervals are 1 K for positive values (full lines) and 0.5 K for negative values (dashed lines). The letters D and W, respectively, refer to dry and wet areas in the surface soil water content analysis (not shown).

5. References

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Smith, C. B., M. N. Lakhtakia, and T.N. Carlson, 1994: Initialization of soil water content in regional-scale atmospheric prediction models. *Bull. Amer. Meteor. Soc.* (in press).